A COMPARISON OF RATE CHANGES IN BASIC MATH SKILLS AND GLOBAL PROCESSING SPEED AMONG ELEMENTARY STUDENTS

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Abstract: The ability to think and solve problems quickly is a necessary skill for success in education (Flanagan, Ortiz, Alfonso, & Mascolo, 2006; Proctor, 2011; Taub, Floyd, Keith, & McGrew, 2008). This leaves students who struggle with speeded tasks at greater risk for not meeting the educational demands in the classroom. Modern intellectual taxonomies, as well as a more thorough understanding of cognitive mediation effects, have led to more reliable identification of these students (Floyd, McGrew, Barry, Rafael, & Rogers, 2009; Kail, 2000, Kail & Salthouse, 1994; McGrew, 2012). However, little-to-no research exists investigating the stability of processing speed (*Gs*) as it pertains to intervention and treatment for *Gs* ability deficits. The following study sought to identify children with low *Gs* ability while intervening daily using a school wide math fluency program with the intent of increasing global *Gs* over time. One hundred seventy-four second and third grade students were administered three *Gs* ability subtests from the WJ-III COG over time to assess *Gs* stability when compared to a control school. Results of the study indicated global *Gs* grew consistently across all *Gs* ability levels for both school groups. Limitations and implications of future research and practitioners are also discussed.

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CHAPTER I

INTRODUCTION

Significance of the Study

The ability to think and solve problems quickly is a necessary skill for success in education (Floyd et al., 2009). However, students who struggle with speeded tasks are at-risk for not meeting the educational demands in the classroom. Modern intellectual theories, as well as a more thorough understanding of cognitive mediation effects, have paved the way for researchers to both identify and intervene with these students as early as possible (Kail, 2000, Kail & Salthouse, 1994). These theories posit that specific cognitive effects, namely working memory (WM) and processing speed (*Gs*), facilitate other aspects of cognitive functioning. Previous research has measured natural development trajectories for *Gs* ability with children and adolescents (i.e., developmental cascades), but researchers have yet to determine the stability of the *Gs* factor. In other words, the current study sought to assess how resistant global *Gs* ability was to change over time. The current study sought to identify children with slow processing speed with the intent to intervene daily using speeded academic tasks to examine the effects on global *Gs* ability

Research Questions

Since limited research has explored the stability of *Gs* ability, or the likelihood to change due to environmental demands over time, the current study sought to investigate how resistant global *Gs* ability was to change over time when subjected to the Explicit Timing (ET) computational fluency to foster growth in basic math skills (BMS) with elementary-age students. Specifically, the following research questions were explored:

1. When compared to a control group, is there a difference between students who participated in daily math fluency enrichment over time?

2. Are there significant differences existed in global *Gs* ability levels over time based upon *Gs* ability membership at the onset of the study?

3. When compared to a control group, do students with low global *Gs* ability who participated in daily math fluency enrichment have comparable or accelerated growth over time?

Research Limitations

This study is an exploratory study that sought to expand research on the *Gs* ability construct; however, its application in both educational and clinical settings is still in its infancy, which lends itself to several limitations. First, the current study required the use of a second school as a comparable control group. Although students were matched based on initial *Gs* ability the environmental contexts of the two schools are not identical. Therefore, the sample was subject to history effects.

Second, progress was measured using the same three *Gs* subtests throughout the duration of the study. Although counterbalanced, the testing effect would certainly influence scores for all levels of both groups. However, the testing effect is assumed to be equal for all groups, so the threat to internal validity is negligible. An alternative would be to use a cross-battery approach, which uses subtests from a variety of intellectual batteries that measure the same construct. However, the current study sought to reduce compounded testing error that would result from using different subtests for each progress monitoring.

Third, math fluency was targeted as a daily speeded task due to its strong correlation with *Gs* ability (McGrew & Wendling, 2010). However, McGrew and Wendling (2010) reported other academic tasks with noteworthy *Gs* factor loadings (e.g., oral reading fluency). Therefore, the generalization of these findings is limited to the effect of computational fluency on global *Gs* ability. Future research should investigate the effects of other *Gs* ability-loaded tasks to further investigate potential treatment effects as well as the stability of the *Gs* factor.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The mission of school psychologists is to provide effective services to help students be successful academically, socially, behaviorally, and emotionally (NASP, 2010). This is primarily accomplished by employing prevention and intervention programming to meet students' needs as quickly as possible (Ysseldyke et al., 2006). While these notions are widely supported, how to best accomplish these goals is still extensively debated; whether it is preferable to focus on individual differences in students or to consider group trends derived from the masses (Fagan & Wise, 2007). This debate was famously delineated by Cronbach (1957) who designated correlational versus experimental scientific psychology, in which correlational studies centered on describing how individual differences related to performance and experimental psychology on specific treatments that yield changes in individual performance. Today, research and practice continue to oscillate between identifying persistent, intrapersonal traits shared by all persons and how applied psychological principles can demonstrate positive changes in specific cases, attributed either to or despite said traits. The current study confronted this dichotomous paradigm by assessing the stability of *Gs* ability when confronted with an applied computational fluency intervention designed to improve math automaticity with students.

Past and Contemporary Theories of Intelligence

Past intellectual theories focused primarily on cognitive products and taxonomical systems rather than cognitive processes, or how specific cognitive abilities interact with one another (Levine, Preddy, & Thorndike, 1986). This zeitgeist was first captured in Charles Spearman's *g* factor research, which claimed general intelligence, or "*g*", was primarily responsible for one's overall cognitive ability on cognitive tasks. Spearman's *g* factor was derived from several positive intercorrelations between subtests measuring sensory discrimination, musical talent, academic performance, and common sense (Wasserman, 2012). He posited that the *g* factor was, in fact, a mathematically derived entity that stemmed from shared variance among contemporary cognitive assessment batteries. Although early research supported this notion, later intellectual theories have shown considerable evidence for more specific intellectual models explaining more variance with regard to cognitive performance. Of note, Louis Thurstone, a noted critic of Spearman's proposed *g* factor, theorized eight primary mental abilities that encompassed one's intellectual capacity: verbal comprehension, word fluency, number facility, memory, visualizing or space thinking, perceptual speed, induction or reasoning and speed of judgment, which was later considered a secondary ability (Thurstone, 1938). While Thurstone and other noted psychologists inevitably accepted the existence of a psychometric *g* factor, Thurstone considered the use of a single score to explain cognitive functioning "inadequate" and argued for the use of a strengths and weaknesses profile (PSW) approach to best explain intellectual ability (Wasserman, 2012). Over time, research focused primarily on hierarchical models of intelligence that steered cognitive research away from psychometric *g* factor explanations and toward specific cognitive abilities as better, more encapsulating intellectual descriptions (McGrew, Flanagan, Keith, & Vanderwood, 1997). This movement continued through the work of Raymond B. Cattell and John L. Horn, who provided evidence that intelligence was comprised of two more narrow abilities: fluid intelligence, or the ability to solve novel problems using induction and deduction independently of acquired knowledge, and crystalized intelligence, or the ability to use one's learned skills as well as recall acquired knowledge and experience (Floyd, Evans, & McGrew, 2003; McGrew & Wendling, 2010; Taub, Floyd, Keith, & McGrew, 2008). This conceptualization was first proposed by Cattell in a 1941 presentation at the annual American Psychological Association (APA) convention where he argued the existence of *Gf* and *Gc* (Wasserman, 2012). Several decades later, Horn expounded his work by charting developmental growth trajectories for *Gf* and *Gc* and expanded the posited cognitive abilities to five (Horn) and six (Cattell). Later work by John B. Carroll (1993) reshaped cognitive taxonomical systems and, ultimately, yielded the Cattell-Horn-Carroll (CHC) Theory of intelligence, which is arguably the most empirically supported model of cognitive structure and ability today.

Cattell-Horn-Carroll (CHC) Theory

CHC theory has continued to shift its orientation toward defining intelligence as a structure of specific cognitive abilities underlying a psychometric *g* factor. Earlier work by Cattell and Horn was further developed on Carroll in the late 20th century. Most noteworthy, Carroll used archival data sets from approximately 461 cognitive assessment batteries to determine the existence of a stable factor structure underlying a century of intelligence tests (Carroll, 1993; McGrew, 2012; Wasserman, 2012). Carroll's seminal study (1993) supported the existence of a multiple-stratum structure that described one's cognitive ability as a hierarchical structure ranging from overall intellectual ability, or *g* factor, to more broad but distinct abilities, to even more narrow abilities that can be further differentiated from one another. Results from Carroll's factor and hierarchical analysis supported the existence of a *g* factor in the third stratum; the second stratum contained eight broad abilities, listed in descending order of strength of association with *g*, including fluid intelligence (*Gf*), crystallized intelligence (*Gc*), general learning and memory (*Gsm*), broad visual perception (*Gv*), broad auditory perception (*Ga*), broad retrieval ability (*Gr*), broad cognitive speediness (*Gs*), and processing speed (*Gt*) (i.e., reaction time); the first stratum contained narrow, singular cognitive ability skills that were nested within each stratum-two ability (Carroll, 1993). While Carroll's work was well received and widely viewed as a breakthrough in cognitive research, Carroll cautioned practitioners about his work that it "paid very little attention to the importance, validity, or ultimate usefulness of the ability factors that have been identified" (Carroll, 2993, p.693). Furthermore, CHC theory posits that cognitive and academic abilities are not mutually exclusive, but rather exist on a continuum that describe some abilities as more easily influenced by the environment (i.e., education) whereas others are more stable cognitive skills that are resistant to change (McGrew, 2012; Flanagan et al., 2006).

Current research on CHC theory has produced sixteen second-stratum abilities that subsume the *g* factor: fluid intelligence (*Gf*), short-term memory (*Gsm*), long-term storage and retrieval (*Glr*), processing speed (*Gs*), reaction and decision speed (*Gt*), psychomotor speed (*Gps*), comprehension-knowledge (*Gc*), domain-specific knowledge

(*Gkn*), reading and writing (*Grw*), quantitative knowledge (*Gq*), visual processing (*Gv*), auditory processing (*Ga*), olfactory abilities (*Go*), tactile abilities (*Gh*), kinesthetic abilities (*Gk*), and psychomotor abilities (*Gp*) (Flanagan, Ortiz, Alfonso, & Mascolo, 2006; McGrew, 2005; McGrew, 2012). Together, CHC theory has validated stable cognitive factors through decades of empirical research.

Although CHC theory holds great promise, future intellectual research continues to move away from taxonomy and toward better understanding cognitive *processes* by integrating developmental and neuropsychological research with modern psychometric literature (McGrew, 2012). Such work has examined specific cognitive factors produced by CHC theory and their potential moderating effects on one another. As a result, new models have been developed that account for a "global mechanism" that consist of stratum-two abilities (e.g., *Gs, Gsm*) that mediate other cognitive factors (Kail, 2000; Kail & Salthouse, 1994).

Processing Speed

Definitions of *Gs* ability range from simple to complex. Horn (1991, p.197) defined *Gs* ability as, "…measured most purely by tests that require rapid scanning and responding to intellectually simple tasks that almost all people would get right if the task were not highly speeded." Later, Carroll (1993) discussed how *Gs* ability was simply the factor that measures speed of cognitive performance, while Flanagan, McGrew, and Ortiz (2000) described the *Gs* factor as the ability to automatically perform cognitive tasks when under pressure to maintain attention and concentration. The current study adopted the *Gs* ability definition presented by Schneider & McGrew (2012), which defined *Gs* as “the ability to perform simple repetitive cognitive tasks quickly and fluently.” To date, five narrow band abilities have been identified that link uniquely and directly with global *Gs* ability: perceptual speed (P), rate-of-test-taking (R9), number facility (N), reading speed (RS), and writing speed (WS) (McGrew, 2005; McGrew, 2012; McGrew, Schrank, & Woodcock, 2007; Schneider & McGrew, 2012).

Perceptual speed (P) is defined as the speed at which stimuli can be compared for similarity or difference (McGrew, 2005). Although perceptual speed is a distinct narrow ability under global *Gs*, studies have reported perceptual speed to be more robust than its peers (McGrew, 2012). Studies have supported this notion by identifying four narrow abilities that further define perceptual speed: pattern recognition, or the ability recognize simple visual patterns; scanning, or the ability to scan and compare visual stimuli; memory, or the ability to perform visual perceptual tasks mentally; and complex, or the ability to perform visual perceptual tasks mentally that require additional cognitive demands. (Ackerman, Beier, & Boyle, 2002; Ackerman & Cianciolo, 2000). Rate-of-test-taking (R9) is defined as the speed and fluency with which simple cognitive tests are completed. The final three stratum-one abilities subsuming *Gs* ability are related to achievement domains. Number facility (N) is defined as the speed at which basic arithmetic problems are completed accurately. Reading speed (RS) is defined as the rate of fluent reading of text with full comprehension. Writing speed (WS) is defined as the rate of which words can be generated or copied.

Age and Gs Ability

As children develop, they process information more quickly (Floyd et al., 2009). However, there are seemingly large differences between age groups from infancy through late adulthood. This missing gap of information has driven many researchers to investigate changes in *Gs* ability throughout human development. The primary finding from this endeavor is that *Gs* ability develops in a linear function beginning in early childhood throughout adolescence (Fry & Hale, 1996; Kail, 1991; Kail & Ferrer, 2007; Nettelback & Burns, 2010). *Gs* ability first becomes a separable cognitive factor between the ages of six and seven (Demetriou et al., 2013; McAuley & White, 2011) with consistent linear growth up until as early as 15 years old (Luna et al., 2004) and as late as 24 years old (Demetriou et al., 2013). After adolescence, both exponential and quadratic functions better represent *Gs* ability (Kail & Ferrer, 2007; McGrew, Schrank, & Woodcock, 2007). To summarize, *Gs* ability does not continue to improve throughout development; speeded ability plateaus and, eventually, decreases with age throughout adulthood (see Figure 2.1).

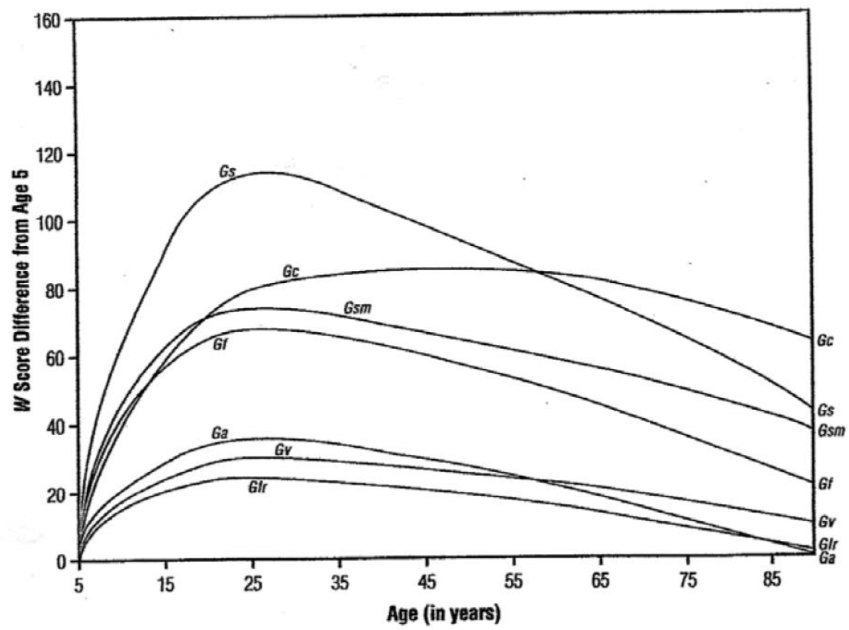

Figure 2.1. WJ III COG Cognitive Factor Growth Curves by Age

Note. *Gs* = Processing Speed; *Gc* = Comprehension-Knowledge; *Gsm* = Short-Term Memory; *Gf* = Fluid Reasoning; *Ga* = Auditory Processing; *Gv* = Visual-Spatial Thinking; *Glr* = Long-Term Retrieval. From McGrew, K. S., Schrank, F. A., & Woodcock, R. W. (2007). *Technical manual. Woodcock-Johnson III Normative Update.* Rolling Meadows, IL: Riverside Publishing.

The secondary finding from this body of research is that *Gf*, working memory (WM), and *Gs* develop in concert throughout childhood and adolescence (Fry & Hale, 2000). Early work by Kail (1991) showed linear growth in *Gs* ability throughout childhood with much slower growth in early adulthood. This early research led to seminal work by Fry and Hale (1996) who measured *Gf*, WM, and *Gs* ability among students between the ages of 7 and 19. Fry and Hale attempted to control for age by matching students from the sample with older students (i.e., seniors in high school and college students) who scored most similarly on each of the three measures in order to examine cognitive changes over time across age groups. Path analyses found that changes in *Gf* ability were dictated by changes in *Gs* ability and WM. Additionally, changes in WM were almost entirely dictated by changes in *Gs* ability. Fry and Hale concluded that a developmental cascade model best explained the data, which stated that *Gf* ability, WM, and *Gs* ability increase in a linear function from early childhood through adolescence. Later research has shown increases in *Gs* ability primarily facilitate growth in *Gf* ability from childhood throughout adolescence (Nettelback & Burns, 2010) as well as mediate gains in other cognitive domains such as executive functioning (Kail, 2007) and attention (Tourva, Spanoudis, & Demetriou, 2016), which further support the presence of a developmental cascade with *Gs* ability.

Gender and Processing Speed

Little is known about gender differences and *Gs* ability. One study by Camarata and Woodcock (2006) investigated differences in *Gs* ability across gender with normative sampling data from a standardized intelligence battery. Their analyses reported females scored significantly higher than males based on mean scores from subtests measuring *Gs* ability. However, no additional studies have been reported to replicate these findings. To date, little research has explored whether these differences exist across the populace.

Math Computational Fluency

According to Haring and Eaton (1978), students must first learn to respond accurately and fluently to problems before generalized responses to novel situations can be made. This hierarchy is most important with individuals who have identified deficits with accurate and fluent responding to academic stimuli. As well, the National Mathematics Advisory Panel (NMAP, 2008) reported American students are failing to demonstrate several key components in mathematics. NMAP identified several key skills necessary to advancing mathematical instruction and achievement in America. Among those skills were "procedural fluency" and "automatic recall of facts." This report revealed the importance of developing automaticity with declarative and procedural mathematical facts. Despite this charge, students who lack computational fluency are at great risk for school failure (NMAP, 2008).

Explicit Timing (ET) Math Intervention

Van Houten and Thompson (1976) first conceptualized the use of explicit timing (ET) procedures to increase fluency. In their study, participants were instructed to complete as many problems as possible in 30 minutes. Participants consisted of 20 students in a second-grade classroom who were identified as having low math performance with basic addition and subtraction facts. The ET timing procedure required participants to underline the last problem completed at the end of each one-minute interval for the duration of 30 minutes. A reversal design was used in this study with overall correct rate (correct problems / 30 minutes), local correct rate (correct problems / actual time), and total problems correct serving as dependent measures. Results showed an increase of 6.8 correct problems per minute once ET procedures were implemented. During the second implementation of ET procedures, rates increased 8.2 correct problems per minute. These results provided initial evidence for the effectiveness of ET as an effective intervention for increasing math fluency.

A study by Rhymer, Skinner, Henington, D'Reaux, and Sims (1998) explored the effects of ET timing on rates of problems completed with math problems in African-American elementary students. A total of 44 students participated in this study. Each child was randomly assigned to one of three groups. These groups were instructed how to use the ET procedure, which was implemented after baseline data were collected. A multiple baseline design was used in the study. The dependent measure of interest was number of problems completed correctly per minute. Results from this study were inconclusive across groups with relation to problems completed correctly per minute. Further analysis revealed rates of completion in Groups 2 and 3 decreased during treatment. Researchers discussed possible reasons for this finding as well as future research with ET.

In a later study, Rhymer, Henington, Skinner, and Looby (1999) compared the effects of using ET procedures with Caucasian and African-American students to increase mathematics performance with basic math facts. This study differed from a previous study by Rhymer, Skinner, Henington, D'Reaux, and Sims (1998) in its research design as well as its dependent measure. In this study, researchers analyzed the data using a within-groups repeated measures ANOVA with race (Caucasian and African-American) and condition (control and experimental) serving as the grouping variables. The dependent measure for this study was total number of completed problems with single-digit addition and subtraction worksheets. Results indicated the experimental group reported a significantly higher number of problems completed than the control group. As well, this finding was consistent across the levels of race. These results suggest using ET can aid in increasing problem completion rates across Caucasian and African-American groups.

Research by Rhymer, Skinner, Jackson, McNeil, Smith, and Jackson (2002) further explored the effectiveness of ET procedures for increasing math performance. In this study, researchers explored the effects of ET with varying levels of math problem difficulty across control and experimental groups. Fifty-four sixth-grade students served as participants for this study with students randomly assigned to one of two conditions: (1) Control or (2) Experimental. Each participant was given all three levels of math difficulty probe: (1) Grade 1.0, (2) Grade 3.5, and (3) Grade 6.0. Grade 1.0 consisted of single-digit addition problems. Grade 3.5 consisted of three-digit minus three-digit subtraction problems. Grade 6.0 consisted of three-digit by three-digit multiplication problems. The dependent measure was problems completed per minute and percent of completed problems that were correct. Results were that participants in the ET group completed significantly more problems correct per minute in the addition and subtraction groups. However, the subtraction group reported minimal increases between the control group (M=10.6) and the experimental group (M=12.1). No significant effects were reported for the multiplication group across condition. As well, no significant differences for percent of completed problems correct were reported. These results suggest that ET is most efficacious with basic math facts.

A study by Rhymer and Morgan (2005) compared the effectiveness of ET and interspersal ratio (IR) interventions. In this study, researchers used a within-subjects design with 45 third-grade students. Control probes consisted of two-digit by two-digit subtraction problems. As well, ET probes consisted of two-digit by two-digit subtraction problems. Lastly, interspersed probes consisted of two-digit by two-digit subtraction problems with single digit subtraction problems interspersed every third target problem. The dependent measures were the rate of total problems completed, the rate of target problems (i.e., 2x2 subtraction) problems completed, accuracy on target problems, and overall student preference for intervention type. Results from this study reported (1) students completed more total problems during the IR condition, (2) rates of target problem completion were highest during the ET condition, (3) accuracy rates were constant, (4) students reported the ET intervention as requiring more time, effort, and being more difficult than the IR condition, and (5) students selected the IR intervention when given the choice. These results provide valuable information as to the effectiveness and efficiency of both ET and IR interventions. Researchers discussed these findings as well as how they apply to the discrete task completion hypothesis for choice behavior.

Research by Clark and Rhymer (2003) compared ET and IR intervention components as a function of math problem completion rates. Participants consisted of 19 university students. Each participant was required to complete math problems associated with each intervention type. For ET, participants were given three minutes to complete as many three-digit minus three-digit subtraction problems as possible. For IR, participants were covertly timed for three minutes while working on three-digit by three-digit subtraction problems with 1-digit by one-digit subtraction problems presented every third problem. The control group received identical packets as the ET group without the expressed time component. This process was implemented for two trials in a counterbalanced order. Researchers used a within-subjects design with levels of condition (control, ET, and IR) administered across each participant. The dependent measures for this study were (1) total math problem completion rates, (2) target problem completion rates, and (3) student preference. Results showed that students completed more total problems during the IR administration. However, students completed more target problems during the ET administration for only one of the trials. As well, students only preferred the IR procedure for one of the trials. This provides partial support for the discrete task completion hypothesis. However, these results support the literature on differences between ET and IR procedures (Rhymer et al, 2002; Rhymer & Morgan, 2005).

A study by Rhymer and Cates (2006) investigated differences in completion rates and student preference between ET and an interspersing procedure. Participants consisted of 187 second-grade students. In this study, participants were required to engage in two math assignments under different conditions. In the ET condition, participants were told to complete math word problems while being overtly timed. In contrast, the interspersal group was required to complete math word problems with short word problems presented every third problem. Participants were covertly timed for the interspersal group. A within-subjects design was used to assess differences across conditions (ET and interspersing). The dependent variables for this study were (1) total number of correct problems, (2) total number of correct target problems, (3) percent of correct target problems, (4) number of seconds required to complete each assignment, and (5) problem completion rate. Student preference was assessed by analyzing student responses to questions post-condition implementation. Results showed that both conditions produced similar correct problem completion rates as well as target problems completed and target problem accuracy. As well, the ET condition reported being the most time intensive and required the most effort to complete. However, no significant difference between the conditions was reported for student preference.

In summary, ET has been shown to be an effective intervention for increasing fluency with basic math facts (Rhymer, Henington, Skinner, & Looby, 1999; Van Houten & Thompson, 1976).

Math Computational Fluency and Gs Ability

A considerable amount of research has been dedicated to investigating reasons why students struggle with academics (Chong & Siegel, 2008; McGrew & Wendling, 2010). Specifically, researchers have investigated whether deficits in *Gs* ability contribute to low achievement in mathematics. Although understanding mathematical concepts and procedures is of growing importance, children with factual deficits in math are at a greater risk than children who struggle with math procedures (Chong & Siegel, 2008). Not only is low *Gs* ability an indicator of low math achievement (Berg, 2008, Chong & Siegel, 2008; Fuchs et al., 2006; Passolunghi, 2011), but also low fluency with basic math facts (i.e., speeded task involving recall of known factual information) is a key distinguisher as well (Mabbott & Bisanz, 2008). These claims are further supported by research on cognitive abilities and their relationship with specific achievement domains. Cognitive factors that are most highly correlated with quantitative knowledge are *Gf*, *Gc*, and *Gs* (McGrew & Wendling, 2010; Taub, Floyd, Keith, & McGrew, 2008). Furthermore, *Gs* ability is most highly correlated with basic math skills (BMS; Floyd, Evans, & McGrew, 2003; McGrew & Wendling, 2010; Proctor, 2011; Taub, Floyd, Keith, & McGrew, 2008). Coupled together, these findings demonstrate the negative impact deficits in *Gs* ability have on math achievement with struggling students.

Proposed Investigation

While previous research has measured natural development trajectories for *Gs* ability with children and adolescents (i.e., developmental cascades), research has yet to investigate the stability of the *Gs* factor. The current study sought to assess how resistant global *Gs* ability was to change over time when subjected to the ET computational fluency to foster growth in BMS with elementary-age students. Due to its exploratory nature, the current study examined the stability of the *Gs* factor across levels of treatment and initial *Gs* ability membership without utilizing an a priori posture; the following research questions were explored to examine potential differences between variables:

1. When compared to a control group, is there a difference between students who participated in daily math fluency enrichment over time?

2. Are there significant differences in global *Gs* ability levels over time based upon *Gs* ability membership at the onset of the study?

3. When compared to a control group, do students with low global *Gs* ability who participated in daily math fluency enrichment have comparable or accelerated growth over time?

CHAPTER III

METHODOLOGY

Research Design

The primary purpose of the current study was to investigate potential changes in global *Gs* ability over a significant period of time. Additionally, the current study sought to identify differences in rate changes between differing ability levels of *Gs* ability. Participants in the current study included students' ages seven years old through nine years old due to the linear growth pattern first identified with young children this age (Fry & Hale, 1996; Kail, 1991; Kail & Ferrer, 2007; Nettelback & Burns, 2010).

Participants and Settings

A total of 287 second and third grade students from two separate schools in Stillwater, OK were eligible to participate in the study. The selection criteria included students who were currently enrolled in grades two or three and who were not currently on an Individual Education Plan (IEP). Students who were on IEPs were not included in the study because their participation in the treatment school's math program was voluntary; therefore, changes in instruction were not comparable across schools when students on IEPs were included. Parents of eligible students were informed of the study (see Appendix B.1) and consent forms were obtained prior to the study implementation (see Appendix B.2). Child assent was also obtained from each participant (see Appendix B.3).

Table 3.1

Recruitment, Participation, and Attrition Rates

	Control School	Treatment School
Total Recruitment	131	156
Initial Participants	94	101
Total Participants	87	87
Attrition Rate	7.4%	13.7%

Participants in the control group (n=87) were from Richmond Elementary (i.e., Control School), a public school in Stillwater, OK. A total of 131 students from second and third grade were eligible to participate in the study from the control school (see Table 3.1). Recruitment forms were sent to parents of all eligible students at the control school and consent forms were obtained prior to implementation. All students with signed parent consent forms were informed of the study and student assent forms were collected. The student assent form was read aloud to participating students, all questions about the study were answered, and signatures were collected. Once all pertinent forms were collected, a total of 94 participants comprised the control group (see Table 3.1). At the conclusion of the study, 87 participants completed all four data collection sessions. The attrition rate for the control group was measured at 8%. Information related to attrition was collected through teacher interviews. Based on teacher report, reasons for attrition consisted of family relocation (n=6) and withdrawal of assent (n=1). With regard to gender, male (n=38) and female (n=49) participants were relatively balanced across the control school. Participant ages ranged from 8-years 1-month to 10-years, 11-months with a mean age of 9-years, 2 months (see Table 3.2).

Participants in the treatment group (n=87) were from Skyline Elementary (i.e., Treatment School), a public school in Stillwater, OK. A total of 156 students from the second and third grade were eligible to participate in the study from the treatment school (see Table 3.1). Recruitment forms were sent to parents of all eligible students at the control school and consent forms were obtained prior to implementation. All students with signed parent consent forms were informed of the study and student assent forms were collected. The student assent form was read aloud to participating students, all questions about the study were answered, and signatures were collected. Once all pertinent forms were collected, a total of 101 participants comprised the control group (see Table 3.2). At the conclusion of the study, 87 participants completed all four data collection sessions. The attrition rate for the control group was measured at 14%. Information related to attrition was collected through teacher interviews. Based on teacher report, attrition consisted primarily of family relocation (n=11) and withdrawal of assent (n=2). Additionally, one student was removed from the study due to concerns regarding the validity of their assessment scores. Specifically, the participant was observed either not participating or explicitly not following subtest directions. As a result, the participant's scores were not included in the analysis portion of the study. With regard to gender, male (n=43) and female (n=44) participants were relatively balanced across the treatment school. Participant ages ranged from 8-years, 1-month to 12-years, 5-months with a mean age of 9-years, 1 month (see Table 3.2).

A separate school was used for the control group for two reasons. First, the treatment school was currently implementing daily math fluency practice at their site. Therefore, it was sensible to measure its continued use there while comparing its effect to a separate control school subsumed by the same district parameters including curricula, academic standards, and policies. By using a comparable control school, the potential confounding variables previously listed are naturally controlled for by using two schools in the same school district. Second, a control group could not be isolated from the rest of the school population at the treatment school since the Math 2-a-days program was implemented schoolwide (i.e., Tier 1) and was designed to benefit all students. Therefore, the control school was determined to be an acceptable and comparable control group for the current study.

Table 3.2

Number, Gender, and Mean Age of Study Participants

	Control School	Treatment School
Males	38	43
Females	49	44
Mean Age	9.24 years	9.09 years
Range	8.13-10.99 years	8.07-12.47 years
SD	0.63 years	0.69 years

Study Procedures

The primary investigator met with teachers at the control school during the first week of school in order to determine appropriate math skills for daily fluency practice. Math fluency data from the previous year was used to determine initial skills for participants who were enrolled at the school previously. Teacher interviews and work samples were used to determine the appropriate initial skill level for all other participants. Students' performance on the initial math skill was monitored using single-skill curriculum-based measurement (CBM) bi-weekly using digits correct per minute (DCPM) and adjusted to ensure each student was responding to the highest instructional-level math skill. For the current study, a participant's highest instructional-level math skill was defined as being no lower than 10 DCPM and no higher than 40 DCPM (Deno & Mirkin, 1977).

Schoolwide Math Fluency Program

Participants from the treatment school engaged in a daily math fluency program developed by school psychology faculty and school psychology doctoral students from a local university (i.e., Math 2-a-days). The Math 2-a-days program utilized the ET intervention to target computational fluency with declarative and procedural math skills. Participants in the treatment group completed two ET intervention sessions each morning in general education classrooms. Each session lasted two minutes for a total intervention time of four minutes per student.

During the ET intervention implementation, participants in the treatment school practiced instructional-level math problems each school day during the 2014-2015 school year. Intervention procedures outlined by Rhymer et al. (2002) were adopted for this study, which implemented the ET intervention with an overt timing procedure for one-minute targeting discrete computation problems. Students were instructed to retrieve their designated math folders each morning over the school's intercom once school had started. A school employee read a scripted protocol over the school's intercom that instructed students to work as many math problems in their folders as fast as possible while doing their best work. This procedure was repeated once more during the morning for a total of two intervention sessions. Once students were finished, classroom teachers collected the folders and scored each session's problems based on DCPM. Scores were written and circled on the student's paper at the top of each page and packets were placed back in the student's folder. Folders were collected by school psychology graduate students at the end of each week. Before the beginning of the next week, students' scores were recalculated for inner rater reliability and inputted in an electronic spreadsheet for data-based decision making purposes. Students who reported 40 DCPM or greater for two consecutive days advanced to the next math skill in the sequence (see Appendix C.1).

To ensure treatment fidelity, all second and third grade classes at the treatment school were randomly observed during the course of the study. Observations were made by the principal investigator and research team members. During observations, the principal investigator and research team members used a treatment fidelity checklist to ensure the ET timing intervention was implemented with consistency (see Appendix B.5). After the ET intervention was completed, teachers were provided with performance feedback based on their level of implementation. All implementation steps that were either absent or incorrectly implemented were discussed with the teacher and a follow-up observation was conducted within one week if implementation fidelity did not exceed 90% of observed intervention steps. This process was repeated until all teachers were observed implementing the treatment with high levels of fidelity.

Woodcock-Johnson Test of Cognitive Abilities, Third Edition (WJ-III COG)

The Woodcock-Johnson Test of Cognitive Abilities, Third Edition (WJ-III COG) is a standardized, norm-referenced cognitive assessment designed to measure the psychometric *g* factor as well as specific cognitive abilities outlined by CHC theory (McGrew, 2012; McGrew, Schrank, & Woodcock, 2007; McGrew & Woodcock, 2001). The WJ-III COG was utilized in the current study due to its adherence to CHC theory as well as its broad sampling of *Gs* ability.

The first subtest, Visual Matching (VM), is a measure of global *Gs* ability that assesses perceptual speed and number facility narrow band abilities underlying *Gs* (McGrew, 2012). Participants were required to identify and circle two matching numbers out of five total numbers. The VM subtest measured an individual's ability to make visual-symbol discrimination. The second subtest, Decision Speed (DS), is also a measure of *Gs* that assesses the perceptual speed narrow band ability. Participants were required to identify and circle correct picture sequences. The DS subtest measured the speed of processing simple concepts (McGrew, 2012). The third subtest, Pair Cancellation (PC), is a dual measure of *Gs* ability and executive processing (i.e., attention/concentration). The PC subtest assessed the attention and concentration narrow band ability for *Gs* abillity (McGrew, 2012). Participants were required to perform a simple cognitive task under time pressure. See Appendix A.1 for subtest information related to *Gs* broad and narrow band affiliation. WJ-III COG *Gs s*ubtests were administered to participants using a within-subjects design over a 120 school day timeline. Since participants were involved in four subtest administrations, the WJ-III COG test-retest reliability scores was reported to justify a repeated measures design. Due to trait stability concerns or *Gs* ability growth over a short period of time (McGrew et al., 1991), the test-retest reliability interval was set at one day in order to reduce changes in *Gs* ability. Median reliability scores for the VM subtest (r=0.87), DS subtest (r=0.80), and PC subtest (r=0.84) all reported strong consistency (McGrew, Schrank, & Woodcock, 2007). These data justify the re-administration of WJ-III COG *Gs* ability subtests using the reported design.

In order to control for *Gs* ability, participants were assessed prior to the onset of the Math-2-a-days program and grouped based on initial *Gs* ability. All participants were group-administered the VM, DS, and PC subtests from the WJ-III COG (see Appendix A.1). By using multiple subtests representing unique narrow band abilities, reported measures of *Gs* ability would most accurately represent participants' true ability for global *Gs*. Likewise, the W-score metric was used to best measure global *Gs* abillity gains over time. W-scores are based on a Rasch model of item response theory, which stipulates that composite scores are an aggregate of individual responses within an assessment, which can be individually weighted to reflect quality of responses (i.e., easier problems have less weight on composite scores than difficult problems) (Woodcock & Dahl, 1971). Unique to the Woodcock-Johnson assessments, W-scores are an interval scale measure that allow for growth to be progress monitored compared to an individual's past performance (McGrew, Schrank & Woodcock, 2007). Traditionally, standardized cognitive assessment yield either scaled or standard scores that are yoked to norming data. These scores have a mean of 100 and a set standard deviation that allows individual scores to be compared to representative population samples. W-scores differ greatly from traditional scaled or standard scores since they do not rely on norm group comparisons. During initial test development, norming data from the WJ-III COG was used to develop a reference point for each subtest based on the average performance of a ten-year-old or 5th grade student. This performance was determined by raw score totals as well as considering item difficulty (e.g., easy, medium, difficult). Mean W-scores were calculated for each subtest on the Woodcock-Johnson assessments, which correspond to the average performance of ten-year-old participant, for age-based comparisons, or a fifth grade student, for grade-based comparisons (McGrew, Schrank & Woodcock, 2007). W-scores have a mean of 500 with no standard deviation. For W-scores below 500, this reflects performance levels less than the average score reported by ten-year-old students in the norming group; the opposite is true for W-scores above 500. By using W-scores, practitioners and researchers can directly assess intra-individual growth over time without norming group comparisons.

In order to best represent global *Gs* ability, three *Gs* subtests were utilized together to comprise an overall measure of *Gs* ability. Mean scores were calculated using the W-scores from the VM, DS, and PC subtests. This method is consistent with WJ-III COG literature, which stipulates that W-scores from commensurate subtests can be averaged together to represent global constructs (McGrew, Schrank, & Woodcock, 2007). Subtests were administered using a randomized partial counterbalancing strategy. Counterbalancing was utilized to reduce confounding error related to retesting and practice effects. A randomized partial counterbalancing technique was used due to the number of subtests used (i.e., three) compared to the number of possible subtest combinations (i.e., six or 3!). Therefore, subtests were randomly ordered differently for each administration.

Data Collection

For the current study, the WJ-III COG *Gs* subtests were group administered to participants. While the WJ-III Technical Manual does not endorse group administration of any subtests from the WJ II COG, it was not feasible to administer the subtests individually in one day. In order to ensure implementation fidelity, a group of school psychology graduate students were recruited to aid in subtest administrations. All research team members had previously completed introductory and advance cognitive assessment courses that included didactic, research, and field-based practicum components. Additionally, recruits were retrained on specific WJ-III COG subtest protocols used in the study.

Subtest administration took place in classrooms with large numbers of participants. In these scenarios, nonparticipating students were given quiet seat work to do during data collection. In contrast, subtest administration took place in a separate location for classrooms with a small number of participants (e.g., empty classroom, library). Prior to administration, participants were instructed to clear their desks except for a single pencil. Participants were then given an assessment packet that contained the VM, DS, and PC subtests. To ensure confidentiality of scores, two participant identification sheets were stapled to the top of the assessment pack. The first sheet contained (1) the participant's name, (2) a unique identification number, and (3) the participant's classroom. All information sheets containing the participants' names were shredded at their respective schools; no identifying information left the school property. During group administrations, each classroom was assigned two recruits to both administer and collect data. One recruit was primarily responsible for reading the WJ II COG subtest instructions, while the second recruit was primarily responsible for monitoring participant responding and answering questions. Each subtest consisted of two parts: (1) practice set problems and (2) clinical set problems. For practice set problems, one recruit would read the subtest instructions. These instructions were followed by prompts for participants to answer a practice problem and receive feedback, which the second recruit would give based on each participant's response. This procedure was repeated for all practice problems. During clinical set problems, both recruits monitored participants' responses to ensure responses were accurate and in compliance with prior instructions. All observed deviations from subtest instructions were corrected (e.g., erasing instead of crossing out changed answers) and participants were notified of start and stop times. Upon completion of the subtests, participants were instructed to remove the information page from the front of their assessment packet and all materials were collected. Group administration of the subtests lasted approximately 20 minutes. To assess growth in *Gs* ability over time, participants were re-administered the WJ-III COG *Gs* subtests at the end of every 30 school days. Data was collected a total of four times with equal intervals between collection dates.

Subtests were scored by the principal investigator and research team members in a locked office containing assessment materials and a desktop computer with installed WJ-

III NU scoring software. Subtests were scored using WJ-III answer overlays that clearly identified correct and incorrect responses. Raw scores were tabulated for each subtest and transferred to a summary score sheet, which was attached to the front of each scoring packet. All summary score sheets contained raw scores as well as the participant's unique identification number and the data collection date. Once raw scores were tabulated, a random sampling of scoring packets were rescored by the principal investigator to ensure scoring reliability.

Data Analysis

A series of Analysis of Variance (ANOVA) tests were conducted to assess the stability of global *Gs* of participants between levels of school membership and across time, while controlling for initial *Gs* ability. The ANOVA test was selected in order to determine whether significant differences existed between the mean scores across each variable. ANOVA is an omnibus test statistic designed to test general rather than specific differences among means using the following null hypothesis statement:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \ldots = \mu_k$$

where μ = group mean and k= number of groups. Significant ANOVA results reject this notion in favor of the alternative hypothesis (H_1), which stipulates that significant differences exist between at least two group means.

School membership (Control, Treatment) and initial *Gs* ability (Below Average, Average, Above Average) served as the between-subjects variables. Initial *Gs* ability was utilized as a blocking variable in order to control for threats to internal validity (e.g., power, error reduction). Therefore, the current study utilized a treatment x block design where participants were matched into ability groups according to initial *Gs* ability mean scores. Finally, global *Gs* served as the within-subjects variable by utilizing a repeated measures design; four measures were taken over the course of 120 school days.

In order to control for initial *Gs* ability, participants were matched to one of three groups. Traditional psychological assessments rely on standard scores (SS) to group individuals into classification groups based on their current functioning level compared to similar peers in a norming group. This is accomplished by calculating z values using the following formula:

$$z = (x - \bar{x}) / \sigma$$

For z values, x is the raw score produced from the subtest, $\bar{x}$ is the sample mean of all reported raw scores, and σ is the sample standard deviation. Since W-scores do not consider standard deviations in their calculations, the current study calculated z values for all participants based on their performance on their first global *Gs* assessment. Once calculated, participants were matched to one of the following groups: (1) Below Average, (2) Average, and (3) Above Average. The parameters for each group were defined as follows: Below Average ($z < -1.33$), Average ($0.67 > z > -1.33$), and Above Average ($z >$ 0.67) (McGrew, Schrank, & Woodcock, 2007; Triola, 2012).

CHAPTER IV

FINDINGS

Introduction

This chapter will present the results of the current study with regard to the proposed research questions. Specifically, the following questions were addressed:

1. When compared to a control group, is there a difference between students who participated in daily math fluency enrichment over time?

2. Are there significant differences existed in global *Gs* ability levels over time based upon *Gs* ability membership at the onset of the study?

3. When compared to a control group, do students with low global *Gs* ability who participated in daily math fluency enrichment have comparable or accelerated growth over time?

Demographic information is presented in Table 4.1. For the current study, collected demographic data was limited to gender and grade due to the exploratory nature of the study. Means, standard deviations, and number of participants for the current study are presented in Table 4.2. In order to control for initial *Gs* ability, participants were matched to one of three ability groups at the onset of the study: (1) Below Average, (2) Average, and (3) Above Average. *Gs* was measured using three subtests from the WJ II

COG measuring *Gs* ability. Subtests were administered using partial counterbalancing in order to reduce differential carryover effects. W-scores were obtained from the three subtests and averaged in order to best represent participants' global *Gs* ability. Participants in the Below Average group (n=59) reported mean W-scores below 475, which corresponded to *z* values below -0.44 and SS below 94. Participants in the Average group (n=53) reported mean W-scores between 476 and 494 which corresponded to *z* values between -0.44 and 0.44 as well as SS between 94 and 107. Finally, participants in the Above Average group (n=62) reported mean W-scores above 495 which corresponded to *z* values above 0.44 and SS above 107. For the current study, growth in global *Gs* was assessed using a repeated measures design in order to compare growth across the two school conditions.

Table 4.1

Demographics of Participants

	Control School		Treatment School	
	N	%	N	%
Gender				
Male	38	21.8%	43	24.7%
Female	49	28.2%	44	25.3%
Grade				
2^{nd} Grade	44	25.3%	56	32.2%
3^{rd} Grade	43	24.7%	31	17.8%

Multiple ANOVA calculations were conducted to answer the current study's research questions. Underlying ANOVA assumptions were met under the following conditions: randomization of students at their respective schools supports independence, sample size provided theoretical evidence of normality, and the Levene statistic was non-significant for three of the four *Gs* measurements (Speed 1: F=6.424 , p < .000) (Speed 2: F=.486, p = .787) (Speed 3: F=.340, p = .888) (Speed 4: F=.608, p = .694) indicating homogeneous variances for these groups. One possible reason for the significant Levene test during the Speed 1 administration could be related to subtest administration. Both research team members and participants were familiar with the subtest administration procedures after the initial Speed 1 test, which would lead to more stable subtest performances. With regard to sphericity, Box's test indicated that the assumption of sphericity has been violated (M = 109.2, p < .000); therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = .799).

Table 4.2

W-Score Means and Standard Error of Treatment and Control Schools

	Control School			Treatment School		
Variables	Mean	Std. Error	N	Mean	Std. Error	N
Below Average	487	.918	27	489	.843	32
Average	496	.936	26	495	.918	27
Above Average	505	.818	34	504	.902	28

Research Question 1

Research Question 1 asked if differences exist between students who participated in daily math fluency enrichment over time compared to a control group of students who did not receive daily computational fluency enrichment. This question was analyzed using a single-factor between-subjects ANOVA. Participants were grouped based on school membership (Control, Treatment) with *Gs* used as a repeated measure across four equal-interval time samplings. Results of the ANOVA showed no main effect between the control and treatment schools, $F(1, 168) = .002$, $p = .962$, $\eta^2 < .000$. See Table 4.3 for marginal means and standard errors.

Table 4.3

Marginal Means for School Membership

	Control School		Treatment School	
	Mean	Error	Mean	Error
Speed 1	488	.450	488	.448
Speed 2	495	.658	492	.655
Speed 3	499	.661	499	.659
Speed 4	501	.837	503	.833

Note. Marginal means contain the average W-Scores from three *Gs* subtests from the WJ-III COG.

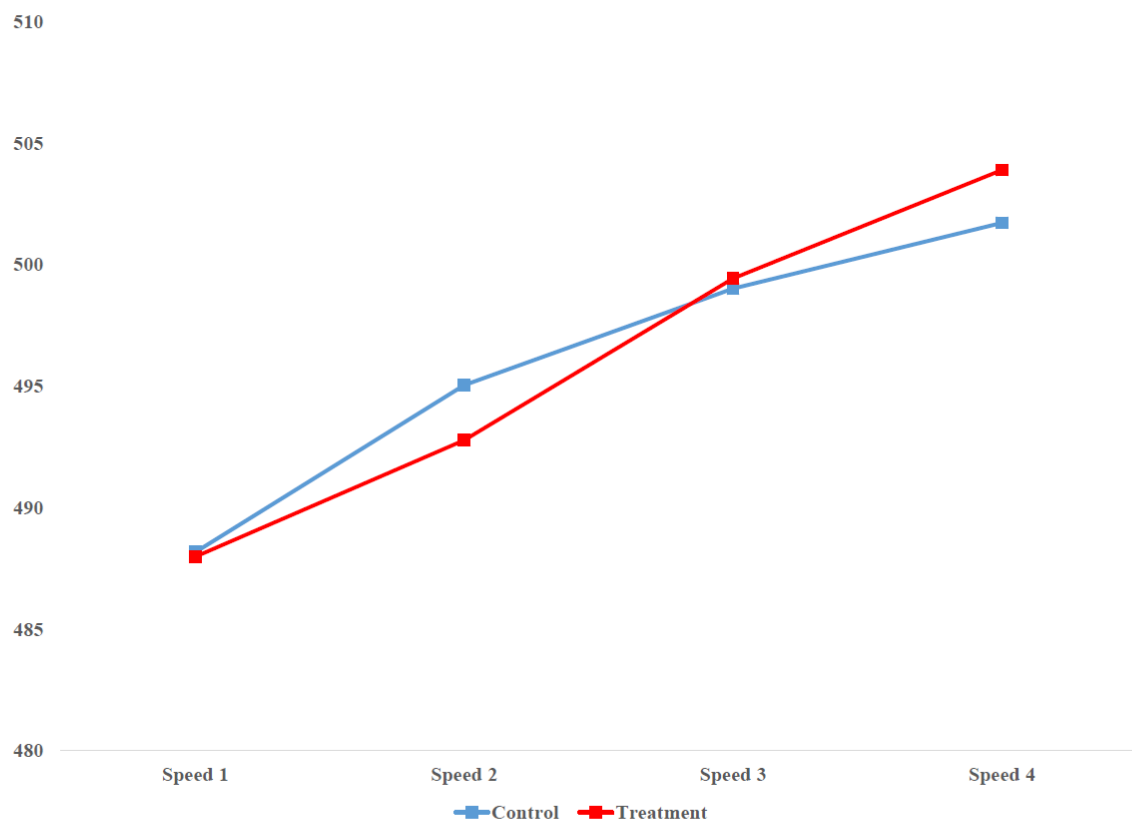

Figure 4.1 Gs Ability Developmental Growth Plots by School Membership

Research Question 2

Research Question 2 asked significant differences existed in global *Gs* ability levels over time based upon *Gs* ability membership at the onset of the study. This question was analyzed using a 2 x 3 Mixed Model ANOVA. Participants were grouped based on school membership (Control, Treatment) and matched based on initial *Gs* ability as a blocking variable (Below Average, Average, Above Average). Four *Gs* measures were used as a repeated measure across four equal-interval time samplings. Results of the ANOVA revealed a significant interaction between *Gs* ability groups and

Gs growth over time, $F(4.80, 402) = 9.75$, $p < .000$, $\eta^2 = .104$. See Table 4.4 for marginal means and standard errors. Due to the statistically significant F-test, a Scheffe post-hoc analysis was employed, which conducted both simple and complex means comparisons. This analysis indicated that all three *Gs* ability levels significantly differed from one another at all *Gs* measurement periods ($p < .000$). See Table 4.5 for post-hoc marginal means and standard deviations.

Additionally, a significant interaction between school membership and *Gs* growth over time was reported, $F(2.40, 402) = 7.11$, $p < .000$, $\eta^2 = .041$. See Table 4.4 for marginal means and standard errors. This analysis indicated that both the Control School and the Treatment School reported statistically significant *Gs* growth time. See Table 4.4 for marginal means and standard deviations. Taken together, these results reveal that participants from both schools reported comparable increases in *Gs* over time regardless of *Gs* membership.

Table 4.4

Marginal Means for School Membership and Global Gs Over Time

	Control School			Treatment School		
	Below Avg	Average	Above Avg	Below Avg	Average	Above Avg
Speed 1	477	488	500	478	488	498
Speed 2	487	494	504	487	491	500
Speed 3	491	499	507	494	498	506
Speed 4	494	502	509	498	503	511

Note. Marginal means contain the average W-Scores from three *Gs* subtests from the WJ-III COG.

Table 4.5

Marginal Means for Initial Gs Ability and Global Gs Over Time

	Below Avg		Average		Above Average	
	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Speed 1	477	.547	488	.578	500	.534
Speed 2	487	.804	494	.849	504	.785
Speed 3	491	.805	499	.849	507	.785
Speed 4	494	1.014	502	1.070	509	.990

Note. Marginal means contain the average W-Scores from three *Gs* subtests from the WJ-III COG.

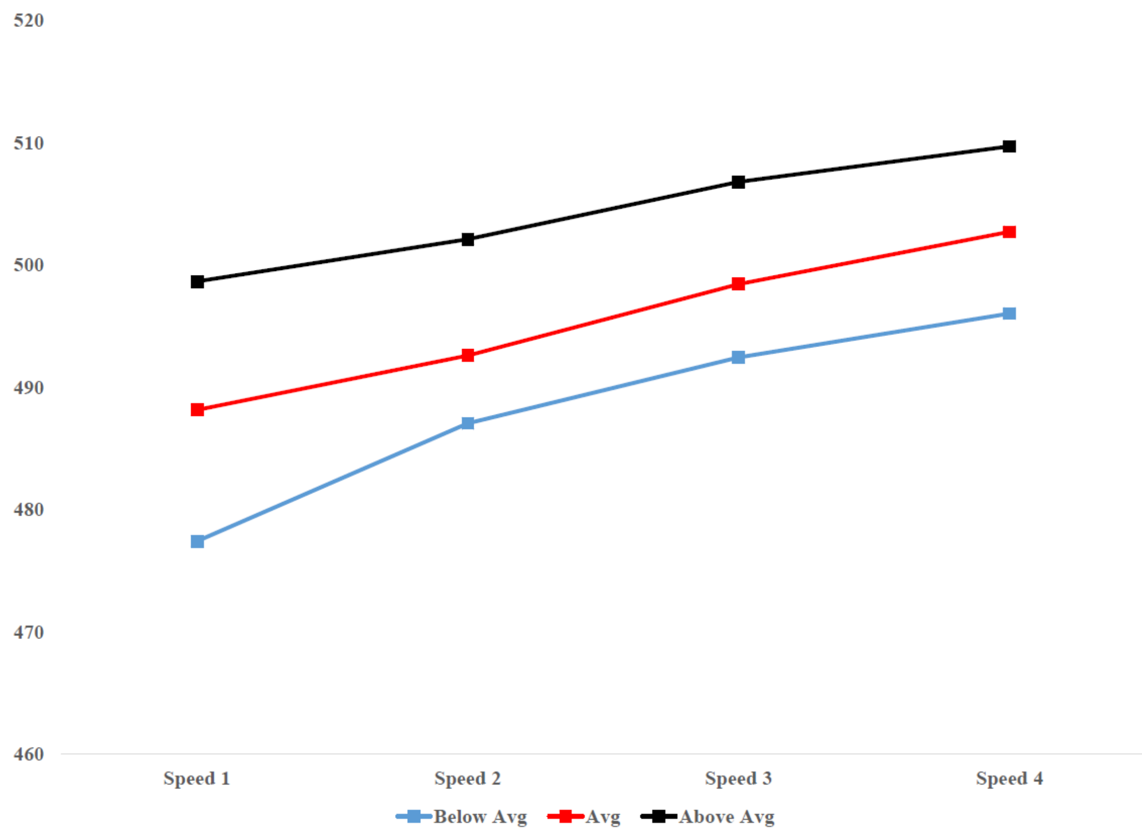

Figure 4.2 Gs Ability Developmental Growth Plots by Initial *Gs* Ability

Research Question 3

Research Question 3 asked whether students with low global *Gs* ability who participated in daily math fluency enrichment have comparable or accelerated growth over time compared to students with low *Gs* ability in the control group. This question was analyzed using a one-way between-subjects ANOVA. Participants from the Below Average *Gs* ability group were compared between group memberships (Control, Treatment). Four *Gs* measures were used as a repeated measure across four equal-interval time samplings. Results of the ANOVA revealed no significant main effect between group membership and participants in the Below Average *Gs* ability group over time, $F(1, 57) = 1.958$, $p = 1.67$. See Table 4.6 for marginal means and standard errors.

Table 4.6

Marginal Means for Below Average Gs Ability and School Membership

	Control School		Treatment School	
	Mean	Std. Error	Mean	Std. Error
Speed 1	477	.802	478	.737
Speed 2	487	1.173	487	1.077
Speed 3	491	1.179	494	1.083
Speed 4	494	1.492	498	1.370

Note. Marginal means contain the average W-Scores from three *Gs* subtests from the WJ-III COG.

CHAPTER V

CONCLUSION

Summary of the Literature

A substantial amount of research over the past half century has sought to answer the “what” questions surrounding cognitive abilities. Early cognitive assessment batteries relied heavily on theoretically based models of intelligence (McGrew, Flanagan, Keith, & Vanderwood, 1997; Thurstone, 1938; Wasserman, 2012). Today, modern intellectual theories, using empirically based intellectual models, have greatly informed how cognitive abilities are both defined and measured (McGrew, 2012; McGrew, Schrank, & Woodcock, 2007). These advancements in measurement have been fueled by a shift from taxonomical systems toward explaining cognitive processes (Levine, Preddy, & Thorndike, 1986). By investigating how intellectual abilities interact with one another, modern cognitive assessments can better describe an individual’s current functioning as well as inform potential supports (McGrew, 2012).

Cognitive processes research has consistently reported that *Gs* and WM function as cognitive mediators that either suppress or enhance other intellectual abilities (Fry & Hale, 1991; Fry & Hale, 2000; Kail, 1991; Kail, 2007; Nettelback & Burns, 2010). According to the developmental cascade model, *Gs* and WM factors develop at a linear rate in conjunction to *Gf*, which both facilitates and mediates growth in other cognitive areas (Fry & Hale, 1996; Kail, 1991; Kail, 2007; Nettelback & Burns, 2010). While *Gf* ability is almost perfectly correlated with psychometric *g* factor (McGrew, 2012) and is assumed persistent throughout the lifespan, research assessing the stability of *Gs* ability has not been conducted.

Deficits in *Gs* ability have profound implications for individuals today, especially in educational settings. The ability to think and solve problems quickly and accurately has quickly become a necessary skill for academic success. This reality leaves students with *Gs* deficits at-risk for not meeting the learning demands of their environment on a daily basis. While current research has focused exclusively on measuring *Gs* developmental trajectories, the current study sought to provide evidence for its *stability* in the presence of academic enrichment, namely math computational fluency. Research on CHC factors and achievement skills reported *Gs* ability is most highly correlated with BMS than any other cognitive factors (i.e., *Gf* and *Gc*), which are only slightly correlated (Floyd, Evans, & McGrew, 2003; McGrew & Wendling, 2010; Proctor, 2011; Taub, Floyd, Keith, & McGrew, 2008). While these findings demonstrate the negative impact deficits in *Gs* ability have on math achievement, a substantial body of research exists demonstrating the positive effects of math fluency-building interventions on increasing computational accuracy and rates with young students. Namely, the ET intervention was designed to build computational fluency with discrete math skills by solely using an overt timing procedure (Clark & Rhymer, 2003; Rhymer & Cates, 2006; Rhymer & Morgan, 2005; Van Houten & Thompson, 1976). By engaging in math sprints targeting instructional-level math skills, studies have repeated demonstrated the ability to increase computational fluency rates in students (cite).

The current study sought to investigate the stability of *Gs* ability by examining its change over time with elementary-age students who participated in daily ET intervention over time. Due to its exploratory nature, the current study examined the stability of the *Gs* factor across levels of treatment and initial *Gs* ability membership without utilizing an a priori posture.

Findings of the Study

Summary of ANOVAs. Analysis of variance tests suggested several interesting findings. The following information was evident from data analyzed with the ANOVA tests: (a) all students reported increases in *Gs* across all levels of *Gs* ability, (b) all *Gs* ability levels grew at commensurate rates over time across both schools conditions, (c) Treatment School participants did not display differentiated growth in *Gs* compared to Control School participants, and (d) Treatment School participants with Below Average *Gs* ability did not display differentiated growth in *Gs* compared to Control School participants with Below Average *Gs* ability.

Research Question 1. Results of the ANOVA showed no main effect between the Control School and Treatment School (See Table 4.3). While both groups showed consistent growth over time, participants receiving daily math enrichment did not display consequential or differential growth in global *Gs*. This finding supports the existence of a developmental cascade model, which stipulates that *Gs* develops as a linear function until early adulthood (Fry & Hale, 1991; Fry & Hale, 2000; Kail, 1991; Kail, 2007; Nettelback & Burns, 2010).

Research Question 2. Results of the ANOVA revealed a significant interaction between *Gs* ability groups and global *Gs* (see Table 4.4). Post-hoc analysis indicated that all three *Gs* ability groups grew at consistent and comparable rates across both school groups over time (see Table 4.5). Again, this finding supports the existence of a developmental cascade model, which stipulates that *Gs* develops as a linear function until early adulthood (Fry & Hale, 1991; Fry & Hale, 2000; Kail, 1991; Kail, 2007; Nettelback & Burns, 2010).

Research Question 3. Results of the ANOVA revealed no significant differences in global *Gs* growth over time for Below Average students from either school condition (see Table 4.6). While both groups of participants demonstrated consistent growth in *Gs* over time, participants in the enrichment condition did not demonstrate consequential or differential growth in global *Gs*. Again, this finding supports the existence of a developmental cascade model, which stipulates that *Gs* develops as a linear function until early adulthood (Fry & Hale, 1991; Fry & Hale, 2000; Kail, 1991; Kail, 2007; Nettelback & Burns, 2010).

Limitations of the Study

This study has three major limitations. The first limitation involved the collection of WJ-III COG subtest data, which was administered in group settings to multiple students at once. According to the test publisher (McGrew, Schrank, & Woodcock, 2007), group administration of these subtests, while not explicitly prohibited, are not endorsed. While reasonable measures were taken to ensure implementation fidelity, additional research is needed to ensure group administration of specific WJ-III COG subtests yield highly reliable data. This research should investigate how standard administration protocols can, or should, be accommodated to allow group administration as well as how reliability scores are affected during group administration

Second, the Math-2-a-days program administered at the Treatment School was a set program designed to build automaticity with BMS; its dose-response prescription was informed primarily by this goal, not growth in global *Gs* ability. While fluency with BMS is strongly correlated with global *Gs*, it is likely that the prescribed dosage of speeded practice (four minutes per day) was not adequate to yield significant differences between the school groups. Additional research is needed to further investigate the stability of global *Gs* ability with varying intervention intensifications (e.g., increased duration, increased daily frequency).

Finally, the current study is exploratory in nature. Its methodology and research design are novel, which inherently pose a threat to internal validity and, consequently, the study's findings. Although empirical and research-based protocols were employed throughout the study, additional research is needed to investigate the methodology reported in this study.

Implications

Implications for Practitioners. While cognitive assessments are traditionally used to determine exceptionality (i.e., cognitive impairments, giftedness) the current study provided support for progress monitoring developmental acquisition of stratum-two cognitive abilities over a given period of time. For exceptional students, practitioners would be able to monitor one's acquisition of these abilities utilizing a within-subject framework versus current functioning level compared to peers alone (standard scores, scaled scores). The current study used W-Score metrics to efficaciously assess construct development over a long duration, which is the first known study to do so. By using a similar process, practitioners could identify and, ideally, remediate deficits in a more meaningful way.

Implications for Researchers. The findings of this study provided strong support for the existence of a developmental cascade model of specific cognitive mediating variables, namely *Gs*. Future research should continue to investigate how these mediation variables affect both global intellectual ability as well as more specific abilities.

Additionally, future research should consider using W-Score metrics to more reliably assess global development of specific cognitive abilities over time. To date, no research studies have employed highly sensitive interval-scaled measures to assess cognitive ability development.

Finally, future research should continue to focus on determining the stability of specific cognitive abilities rather than merely their products. This research should be done in order to directly inform potential treatments for individual experiencing cognitive impairments that negatively affect daily life. To date, little-to-no evidence exists to support cognitive interventions for these delays; research on how resistive specific cognitive abilities are is greatly needed.

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APPENDICES

APPENDIX A.1

WJ-III COG Subtests for *Gs*, CHC Factors, and Descriptions

Test	Description
Visual Matching **Processing Speed (*Gs*)** *Perceptual Speed (P)*	Measures speed in making visual symbol discrimination.
Rapid Picture Naming **Processing Speed (*Gs*)** *Naming Facility (NA)*	Measures speed of direct recall of names from acquired knowledge.
Pair Cancellation **Processing Speed (*Gs*)** *Attention and Concentration (AC)*	Measures the ability to control interferences, sustain attention, and stay on task in a vigilant manner by locating and marking a repeated pattern as quickly as possible.
Cross Out **Processing Speed (*Gs*)** *Perceptual Speed (P)*	Measures the ability to scan and compare visual information quickly.
Decision Speed **Processing Speed (*Gs*)** *Semantic Processing Speed (P4)*	Measures the ability to make correct conceptual decisions quickly.

Note. From "*Contemporary intellectual assessment: Theories, tests, and issues"* by Flanagan, D. P. & Harrison, P. L. (pp. 298-299). New York: Guilford.

APPENDIX B.1

Recruitment Script Letter

Dear Parents,

Hello, my name is Sean Simons. I am a graduate student at OSU in the School Psychology Department. I am interested in the effects of math fact practice and global processing speed with elementary-age students. Global processing speed is defined as the ability to perform simple repetitive cognitive tasks quickly and fluently. This skill is required to complete math problems fluently. Math fluency is the ability to complete target math problems both accurately and quickly. Because this study requires research, I am seeking your consent to include your child in my study.

Participation in this research includes completing four measures of processing speed, which take a total of twenty minutes to complete. These measures will require your child to do simple tasks as quickly as possible, such as circling two things that look alike from a small group of pictures. These measures will be given a total of four times throughout the school year, exactly once every thirty school days.

Participation in this study is voluntary and your child can withdrawal at any point. There are no known or foreseen risks for participants in this study, and your child's instruction will not be affected in any way.

If you have any questions or would like to participate in the research, I can be reached at (512) 574-8378 or by email at sean.simons@okstate.edu

Thank you very much.

Sincerely,

Sean Simons, M.S.	Terry Stinnett, Ph.D.
Doctoral Candidate	Faculty Advisor
Oklahoma State University	Oklahoma State University

APPENDIX B.2

Parent Consent Form

PROJECT TITLE: A Comparison of Rate Changes in Basic Math Skills and Global Processing Speed Among Elementary Students

INVESTIGATOR(S): Sean Simons, M.S. – Doctoral Candidate; Terry Stinnett, Ph.D. - Advisor

PURPOSE:

The purpose of this study is to explore the effects of daily math fluency practice on global processing speed. Specifically, our main research question is to measure whether practicing timed math problems every day has a measurable effect on how quickly children think in general. We must use research to answer this question, which is impossible without willing students and parents. For this reason, we ask your consent for your child to participate in our study.

PROCEDURES:

During the study, your child will either be in the treatment or control school. The treatment school will participate in a daily math fluency program where students will practice instructional-level math problems each day throughout the school year. Students in the treatment school will practice math problems twice-a-day for a total of 4 minutes. Students in the control school will receive normal instruction.

Every 30 days, your child will be asked to respond to four tests that measure processing speed. These tests will be group administered, and they will not be administered during your child's instructional time. An example of a task your child will be asked to do is to circle two things that are most alike from a small group of pictures. Test administration will take a total of 20 minutes, and it will occur a total of four times throughout the school year.

RISKS OF PARTICIPATION:

There are no known risks associated with this project, which are greater than those ordinarily encountered in daily life.

BENEFITS OF PARTICIPATION:

There are no direct benefits to your child for participation. The results of this study, however, will increase our understanding of the effects of daily math practice.

CONFIDENTIALITY:

The records of this study will be kept private. Any identifying information (ex: your child's name, school ID) will not leave the school building. All identifying information will remain locked in the school psychologist's office at your child's school. Only the researchers will have access to these records during the study. After the study is concluded, all identifying information will be destroyed, and all non-identifying information will be kept stored in a locked office at Oklahoma State University according to their compliance standards. Any written results will discuss group findings and will not include information that will identify you or your child. Research records will be stored on a password-protected computer in a locked office and only researchers and individuals responsible for research oversight will have access to the records. Due to these safeguards, there are no foreseeable risks to maintaining confidentiality.

CONTACTS:

You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study:

Sean Simons, M.S.	Terry Stinnett, Ph.D
Doctoral Candidate	Faculty Advisor
Oklahoma State University	Oklahoma State University
(512) 574 -8378	(405) 744-5474
sean.simons@okstate.edu	terry.stinnett@okstate.edu

If you have questions about your rights as a research volunteer, you may contact Dr. Tamara J. Mix, IRB Vice-Chair, 219 Cordell North, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

PARTICIPANT RIGHTS:

I understand that my child's participation is voluntary, that there is no penalty for refusal to participate, and that I am free to withdraw my permission at any time. Even if I give permission for my child to participate I understand that he/she has the right to decline.

CONSENT DOCUMENTATION:

I have been fully informed about the procedures listed here. I am aware of what my child and I will be asked to do and of the benefits of my participation. I also understand the following statements:

I have read and fully understand this permission form. I sign it freely and voluntarily. A copy of this form will be given to me. I hereby give permission for my child ________-____________ participation in this study.

Signature of Parent/Legal Guardian Date

APPENDIX B.3

Child Assent Form

Dear Student,

We are interested in learning about how practicing math problems every day affects how quickly children your age think. In order to understand this, we would like you to take some short tests that measure how fast you solve problems.

If you choose to participate, then you will be asked to take four tests every thirty days that measure how quickly you solve simple problems. An example from one of these tests will ask you two circle two things that are most similar from a small group of pictures.

Please understand that you do not have to do this. Your parents have given us permission to ask you to participate, but you have the right not to participate if do not wish to. You do not have to answer any questions that you do not want to. You may stop at any time.

Your name will not be on the forms you fill out, and you will be given a number that will be put on your answer sheet so no one will know whose answers they are. Any information that has your name on it will not leave the school building. The only way anyone would know how you answered is if we are worried about you, and then we would call your parent/guardian. This would only occur if we felt that you were in danger. Otherwise, your work will remain private. If you have any questions about this form or what we are doing, please ask us. Thank you for your help.

Sincerely,

Sean Simons, M.S.	Terry Stinnett, Ph.D.
Doctoral Candidate	Professor
Oklahoma State University	Oklahoma State University

I have read this form and agree to help with your project.

____

(your name)

____

(date)

APPENDIX B.4

IRB Approval Letter

Oklahoma State University Institutional Review Board

Date:	Tuesday, September 09, 2014
IRB Application No	ED14100
Proposal Title:	A Comparison of Rate Changes in Basic Math Skills and Global Processing Speed Among Elementary Students
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved Protocol Expires: 9/8/2015

Principal Investigator(s):

Sean P. Simons	Terry Stinnett
1308 S Duck St	445 Willard
Stillwater, OK 74075	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☐ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1.Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2.Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3.Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4.Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Cordell North (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Hugh Crethar, Chair
Institutional Review Board

APPENDIX B.5

Treatment Fidelity Checklist

□ A schoolwide announcement is made regarding Math-2-a-days

□ All students are seated with appropriate materials on their desk

  □ Math folder
  □ Pencil

□ Scripted directions are read over the school intercom

□ During ET intervention session #1

  □ All students were observed actively working on math problems for the entire 2-minute duration
  □ All student started and stopped working when prompted

□ During ET intervention session #2

  □ All students were observed actively working on math problems for the entire 2-minute duration
  □ All student started and stopped working when prompted

□ The teacher collected the math folders and all student questions were answered

Boxes Checked: ____ / 12

Observed Fidelity: ____ %

Treatment fidelity was discussed with teacher on ___________ (date) by

____________________ (name).

APPENDIX C.1

Math Scope and Sequence

1. Number Writing
2. Missing Number
3. Addition to 6
4. Addition to 9
5. Subtraction from 10
6. Addition to 18
7. Subtraction from 20
8. 2 x 2 Addition
9. 2 x 2 Addition with Regrouping
10. 2 x 2 Subtraction
11. 2 x 2 Subtraction with Regrouping
12. Multiplication to 81
13. Division from 81
14. 2 x 1 Multiplication
15. 2 x 2 Multiplication

Note. Scope and sequence was created by school psychology faculty and school personnel. Considerations for curriculum, teacher feedback, and developmental acquisition of math skills were used in its development.

VITA

Sean Peter Simons

Candidate for the Degree of

Doctor of Philosophy

Thesis: EMPIRICALLY VALIDATED MATHEMATICS INTERVENTIONS FOR INCREASING ACCURACY AND FLUENCY WITH BASIC MATH FACTS

Major Field: Educational Psychology

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Educational Psychology (Option: School Psychology) at Oklahoma State University, Stillwater, Oklahoma in May, 2017.

Completed the requirements for the Master of Science in Educational Psychology (Option: School Psychometrics) at Oklahoma State University, Stillwater, OK in December, 2012.

Completed the requirements for the Bachelor of Arts in Psychology at Harding University, Stillwater, OK in May, 2011.

Experience:

External Coach for the Oklahoma Tiered Intervention System of Support grant

Behavior Specialist at Applied Behavior Analysis of Oklahoma

Completed 1,200+ Practicum Hours in School, Clinical, and Outpatient Settings

Professional Memberships:

American Psychological Association Div. 16 (2012 – present)

National Association of School Psychologists (2011 – present)

Oklahoma School Psychology Association (2011 – present)